Rating curves and estimation of average water depth at the upper Negro River based on satellite altimeter data and modeled discharges

Juan Gabriel Leon, Stéphane Calmant, F. Seyler, Marie-Paule Bonnet, Mathilde Cauhopé, Frédéric Frappart, Naziano Filizola, Pascal Fraizy

Tables

Table 1 Principal characteristics of Negro River

Negro Basin	
Area	715,000 km^2
Mean annual temperature	26 °C
Annual rainfall	3000—4000 mm
Soil moisture regime	Udic to Perudic
Rainfall peak period	April—June
Discharge Ranges	4200—50,000 m^3/s

Soil Survey Staff (1975, 1990), Dubroeucq and Volkoff (1998) and Guyot (1993).

Table 2 Main characteristics of hydrologic stations studied

Station name	River	Longitude	Latitude	Measurement period	Discharge (m^3/s)	Drained area (km^2)	Upstream station
Cucui	Negro River	−66.8597	1.2155	1980–2204	400–10,500	70,400	–
Sao Felipe	Negro River	−67.3218	0.3727	1977–2004	1200–15,500	119,200	Cucui
Curicuriari (from Sao Felipe)	Negro River	−66.8115	−0.1921	1977–2004	2500–24,000	132,000	Sao Felipe
Curicuriari (from Taraqua)	Negro River	−66.8115	−0.1921	1977–2004	2500–24,000	132,000	Taraqua
Serrinha Curicuriari	Negro River	−64.8108	−0.4876	1977–2004	5000–30,000	283,000	
Uaracu		−69.1388	0.4892	1977–2004	80–6000	38,700	–
Taraqua	Uaupes River	−68.5534	0.1349	1977–2004	250–6500	42,000	Uaracu

Table 3 Principal characteristics of the virtual stations

Station	River	Latitude/longitude	Type of data	Dry/wet season cross-section width (km)	Discharge measured by ADCP in 05/2005 (m^3/s)	Average water depth by ADCP in 05/2005 (m)	Upstream In situ station distance (km)
T493_1	Negro	0.87/−66.89	ENVISAT	1.72/2.23	7071	8.23	Cucui (47)
T89_22	Negro	0.91/−67.00	T/P	1.4/2.08	7071	8.40	Cucui (60)
T536_1	Negro	0.92/−67.19	ENVISAT	0.76/1.29	7623	10.18	Cucui (85)
T536_2	Negro	0.72/−67.23	ENVISAT	1.02/1.98	8582	11.43	Cucui (113)
T536_3	Negro	0.60/−67.26	ENVISAT	0.98/2.19	8647	9.32	Cucui (128)
T536_4	Negro	0.37/−67.31	ENVISAT	1.06/2.19	11,625	12.24	Sao Felipe (0)
T89_26	Negro	0.09/−67.29	T/P	0.8/0.84	12,524	11.95	Sao Felipe (33)
T994_1	Negro	−0.23/−66.73	ENVISAT	1.12/1.52	18,590	12.92	Curicuriari (10.6)
T493_2	Negro	−0.33/−66.62	ENVISAT	2.16/2.48	18,569	11.49	Curicuriari (26.5)
T450_1	Negro	−0.32/−66.03	ENVISAT	3.65/3.65	20,361	7.58	Curicuriari (100)
T951_1	Negro	−0.31/−65.91	ENVISAT	1.81/2.06	20,445	11.10	Curicuriari (114)
T254_22	Negro	−0.24/−65.81	T/P	2.72/7.70	21,841	11.48	Curicuriari (126)
T908_1	Negro	−0.37/−65.32	ENVISAT	2.91/2.91	22,388	12.44	Curicuriari (188)
T407_1	Negro	−0.41/−65.15	ENVISAT	2.44/2.44	23,460	11.78	Curicuriari (207)
T121_1	Uaupes	0.43/−68.94	ENVISAT	0.8/1.29	No data	No data	Uaracu (50.3)
T178_7	Uaupes	0.43/−68.89	T/P	0.98/0.98	No data	No data	Uaracu (57)
T622_1	Uaupes	0.35/−68.75	ENVISAT	1.06/1.69	No data	No data	Uaracu (80.4)
T579_1	Uaupes	0.12/−68.16	ENVISAT	1.21/2.64	4850	5.48	Taracua (60)
T78_1	Uaupes	0.11/−68.09	ENVISAT	1.42/1.42	4791	6.13	Taraqua (69)
T35_1	Uaupes	0.11/−67.45	ENVISAT	0.89/1.41	5190	8.98	Taraqua (160)
T536_5	Uaupes	0.09/−67.36	ENVISAT	1.02/1.34	5204	10.6	Taraqua (168)

Table 4 Results of the method application at three gauged stations

Station	a	b	R^2	EWD (m)	GWD (m)	D1 (m)	D2 (m)	Difference between D1 and D2
Cucui	314.21	1.502	0.99	7.99	9.82	1.83	2.12	−0.29
Sao Felipe	179.08	1.86	0.97	11.53	11.75	0.22	−0.19	0.41
Curicuriari	33.13	2.495	0.96	13.6	11.03	2.57	0.73	1.84
Serrinha	105.73	2.308	0.94	10.83	11.78	0.95	0.77	0.19

GWD, gauged water depth at in situ station for the same discharge measured by the ADCP in 05/2005; EWD, estimated water depth by the rating curve for the same discharge measured by ADCP; D1, difference between GWD and EWD; D2, difference between GWD and MWD.

Table 5 Results of the rating-curve and water depth estimations at virtual stations

Station	a	b	z (m)	R^2	n	Average estimated water depth	EWD (m)	Difference between MWD and EWD (m)	σ_d (m)
T493_1	594.08	1.26	70.04	0.98	17	4.68	7.26	0.97	1.38
T89_22	339.83	1.25	67	0.66	86	8.85	8.28	0.12	1.48
T536_1	412.92	1.35	68.80	0.99	16	6.07	8.66	1.52	3.48
T536_2	105.21	1.79	65	0.90	19	8.25	11.74	−0.3	3.00
T536_3	206.56	1.63	66.34	0.98	18	6.85	10.05	−0.72	1.61
T536_4	179.08	1.86	65.29	0.97	18	8.38	10.95	1.30	4.1
T89_26	115.64	2.01	59.5	0.79	98	9.64	9.01	2.94	7.04
T994_1	204.92	1.87	36.51	0.99	15	8.12	11.01	0.72	5.45
T493_2	257.14	1.79	35.90	0.98	15	8.04	10.80	−0.69	3.76
T450_1	383.90	1.76	31.83	0.99	15	7.32	9.54	−1.95	2.57
T951_1	422.10	1.73	30.29	0.99	15	6.93	9.42	1.68	8.3
T254_22	1576	1.001	25	0.76	94	10.23	11.87	−0.39	4.67
T908_1	490.52	1.71	25.29	0.98	18	7.21	8.82	−1.16	2.44
T407_1	553.80	1.67	24.67	0.99	15	7.01	9.37	−2.41	4.54
T121_1	529.41	1.35	89.79	0.97	14	3.88	–	No MWD data	–
T178_7	340.95	1.41	88.29	0.72	59	4.23	–	No MWD data	–
T622_1	768.88	1.25	89.79	0.96	13	2.33	–	No MWD data	–
T579_1	175.80	1.71	73.97	0.99	13	4.55	6.78	−1.28	2.69
T78_1	410.41	1.36	74.11	0.97	14	4.72	6.092	0.04	3.26
T35_1	298.13	1.26	66.17	0.95	16	6.25	9.69	−0.71	3.94
T536_5	121.58	1.55	63.92	0.95	16	7.71	11.28	−0.68	3.45

GWD, gauged water depth at in situ station for the same discharge measured by the ADCP in 05/2005; EWD, estimated water depth by the rating curve for the same discharge measured by ADCP; MWD, measured average water depth by ADCP under each altimetric track in 05/2005; a, b, coefficients of the rating curve (Eq. (4)); z, estimated zero effective flow stage from the ellipsoid WGS84 by RMSE minimization method; R^2, correlation coefficient of the rating curve; n, number of points in the rating curve; σ_d, standard deviation of the depth along the ADCP profile.

Table 6 Manning roughness coefficient along the Negro and Uaupes Rivers

Reach	Reach number	*n* (dry season)	*n* (rain season)
T493_1—T536_4	1	0.04	0.076
T89_26—T994_1	2	0.093	0.11
T493_2—T254_22	3	0.037	0.04
T908_1—T407_1	4	0.032	0.032
T121_1—T536_5	5	0.036	0.054

Figures

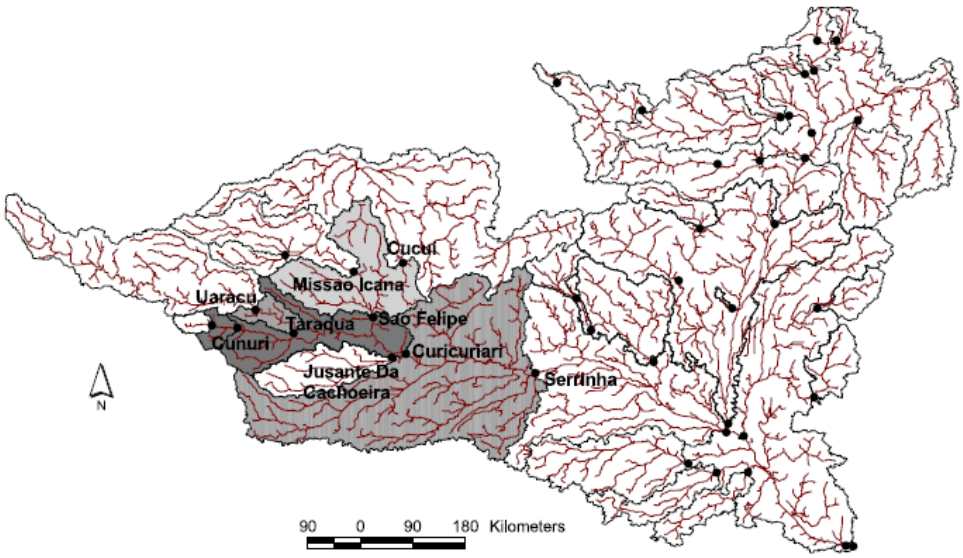

Figure 1 Negro River Basin. The Negro River and the subwatershed delineation. Black points show the position of the hydrological stations in the basin. In grey are the subwatersheds considered in this study.

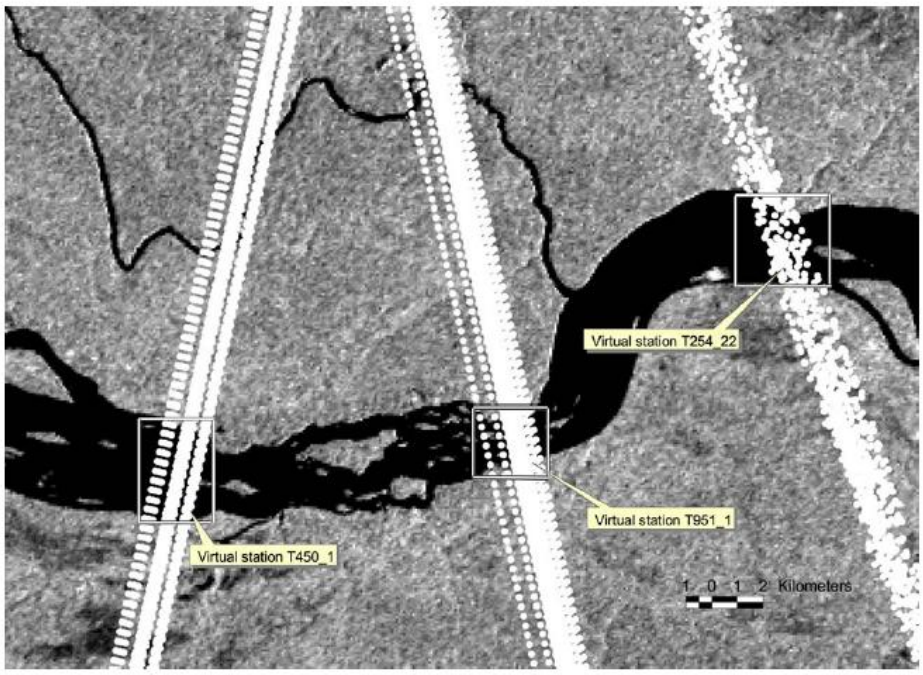

Figure 2 Virtual stations. Virtual stations selection data based on JERS image ENVISAT and T/P level measurements. The zone showed is located between Curicuriari and Serrinha in situ stations in dry season.

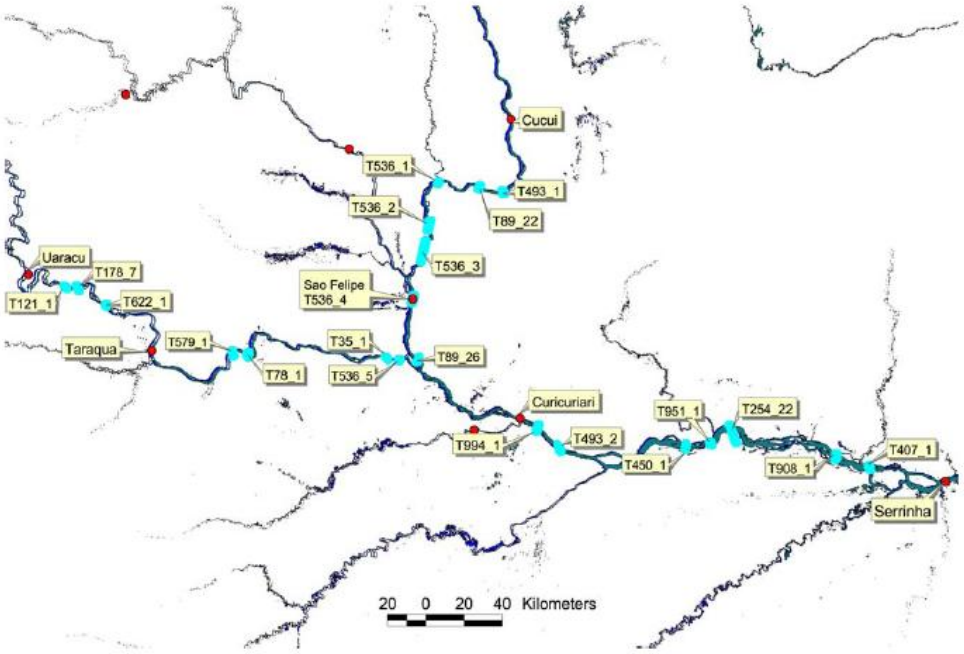

Figure 3 Virtual stations. Position of virtual stations between Cucui and Serrinha for the Negro River main stream and Uaracu et Curicuriari for the Uaupes River main stream.

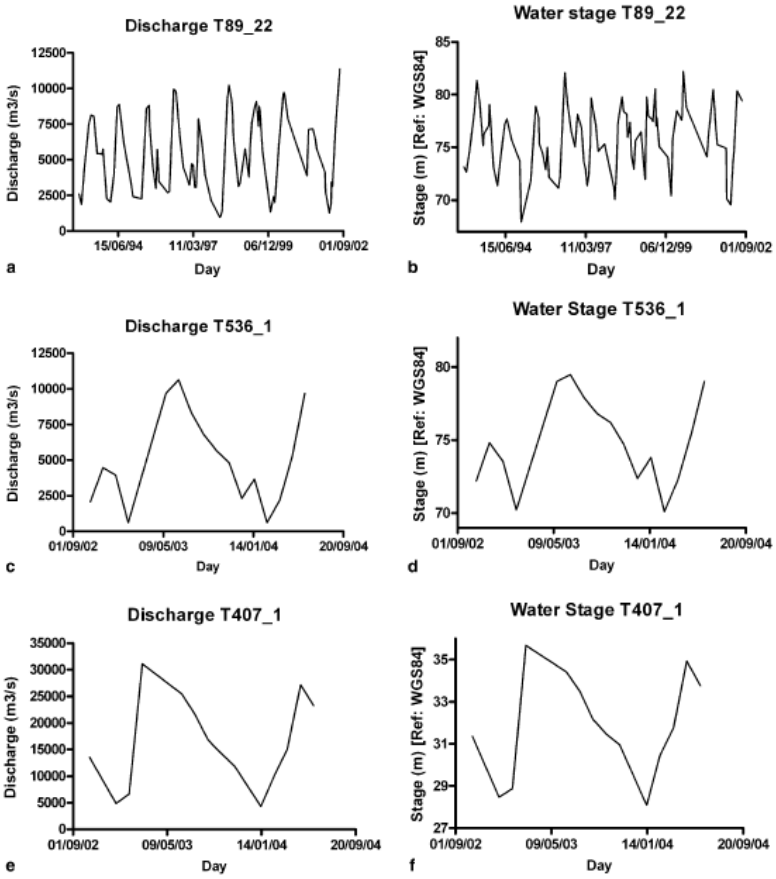

Figure 4 Discharge and water stage time series. Discharge and water stage time series of three virtual stations along the Negro River main stream.

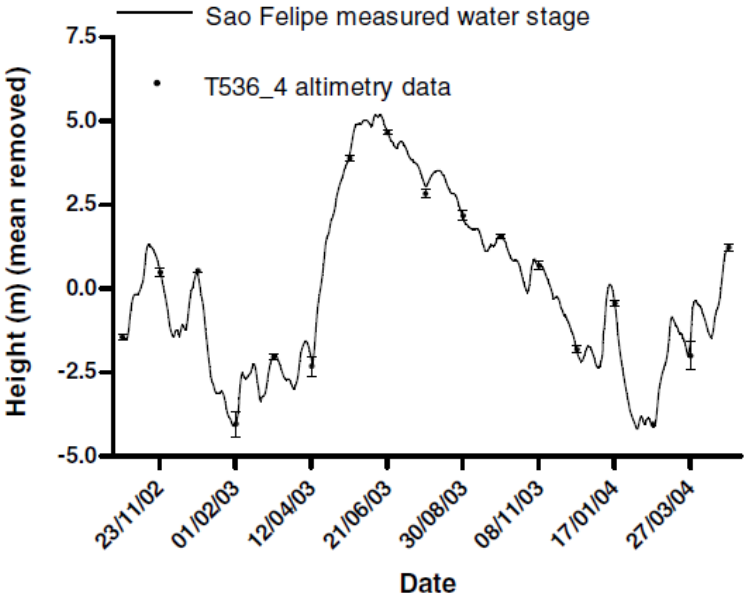

Figure 5 Time series of water stage at Sao Felipe. The thin continuous line stands for the daily in situ readings. ENVISAT heights (black dots) are reported as the median value at each pass (every 35 days) along with the standard deviation.

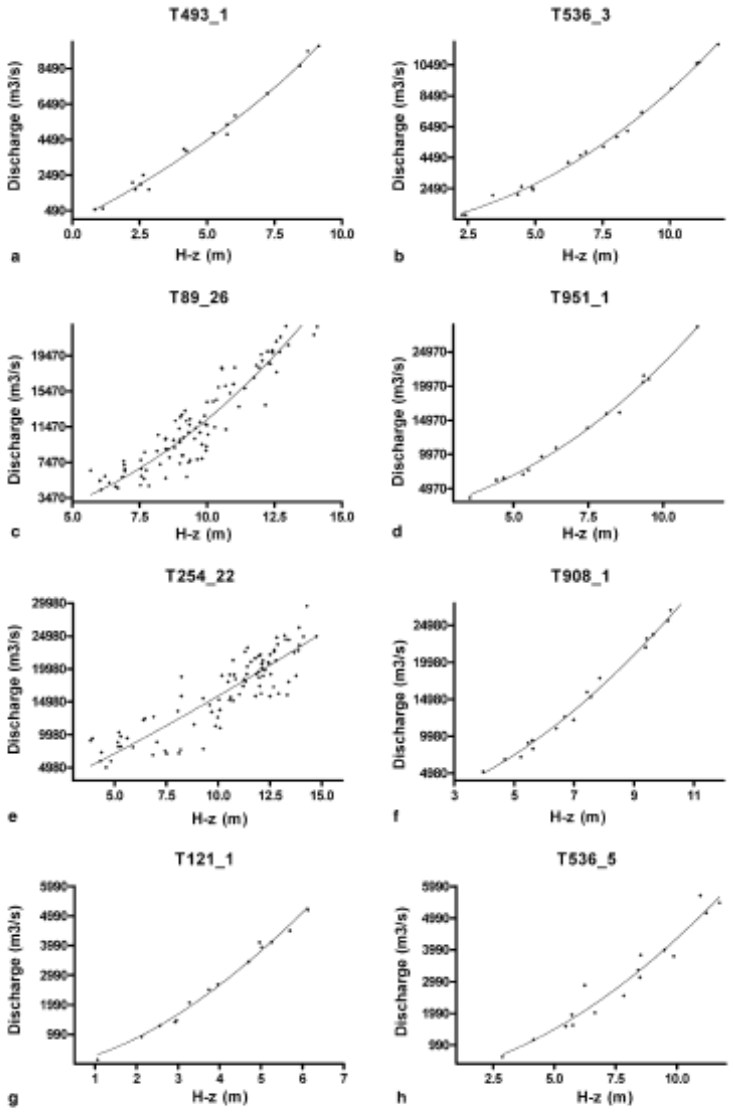

Figure 6 Estimated rating-curves. Example of estimated rating-curves for some virtual stations.

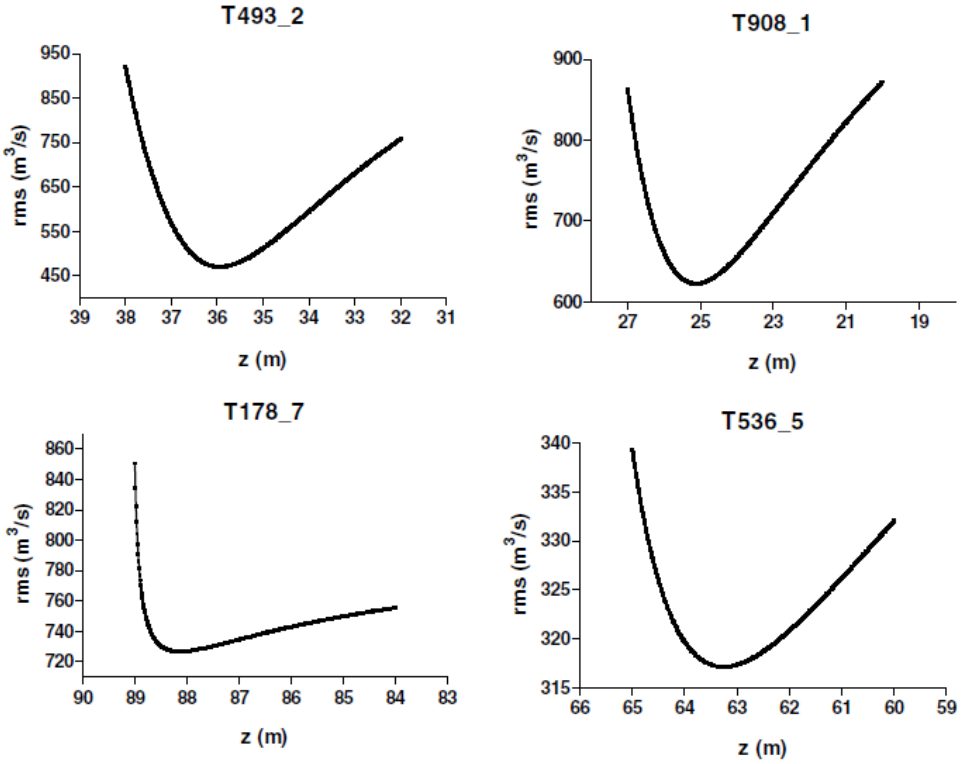

Figure 7 RMS evolution. Evolution of the RMS in discharge when the discharge—height pairs are fitted by a rating curve for successive values of the reference depth z.

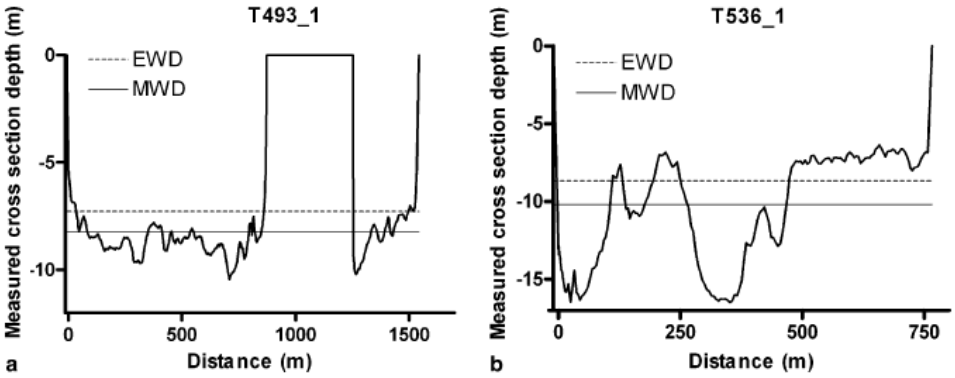

Figure 8 ADCP profiles from Cucui to Sao Felipe station (following down the Rio Negro). Measured profiles by ADCP in May 2005 for the virtual stations located between Cucui and Sao Felipe.

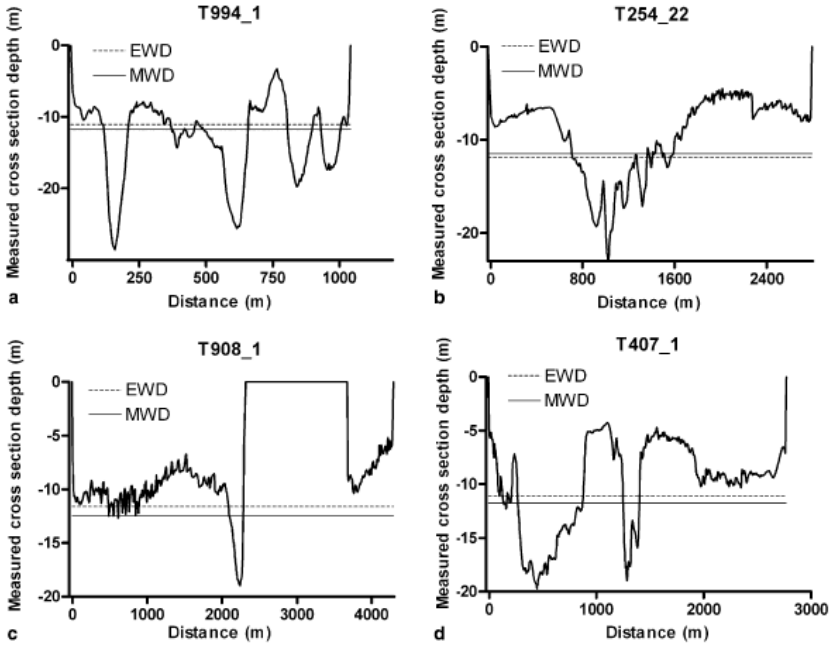

Figure 9 ADCP depth profiles at the virtual stations (following the Rio Negro, from Sao Felipe to Serrinha). Profiles collected in May 2005.

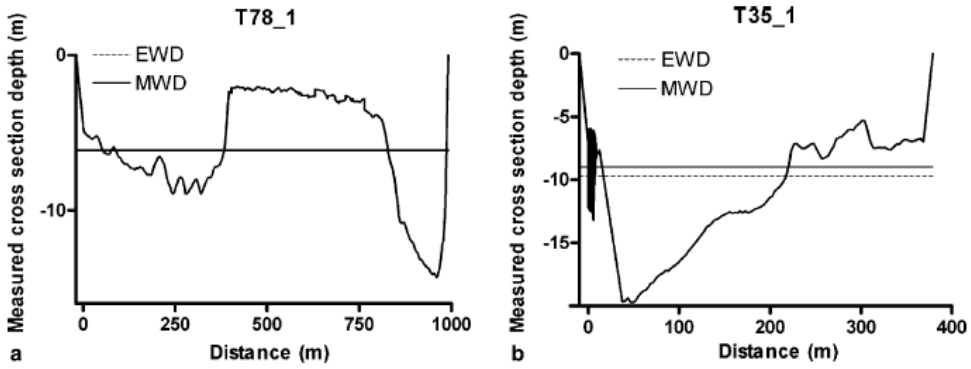

Figure 10 Uaupes River profiles. Measured profiles by ADCP in May 2005 for the virtual stations located at Uaupes River main stream.

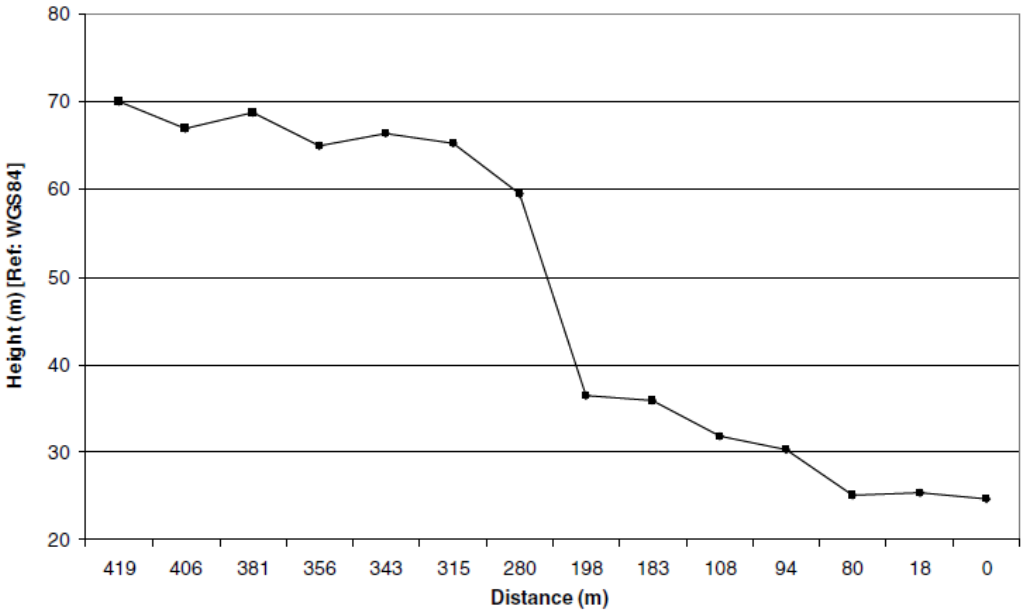

Figure 11 Negro River bed slope. Upper Negro River bottom slope profile.

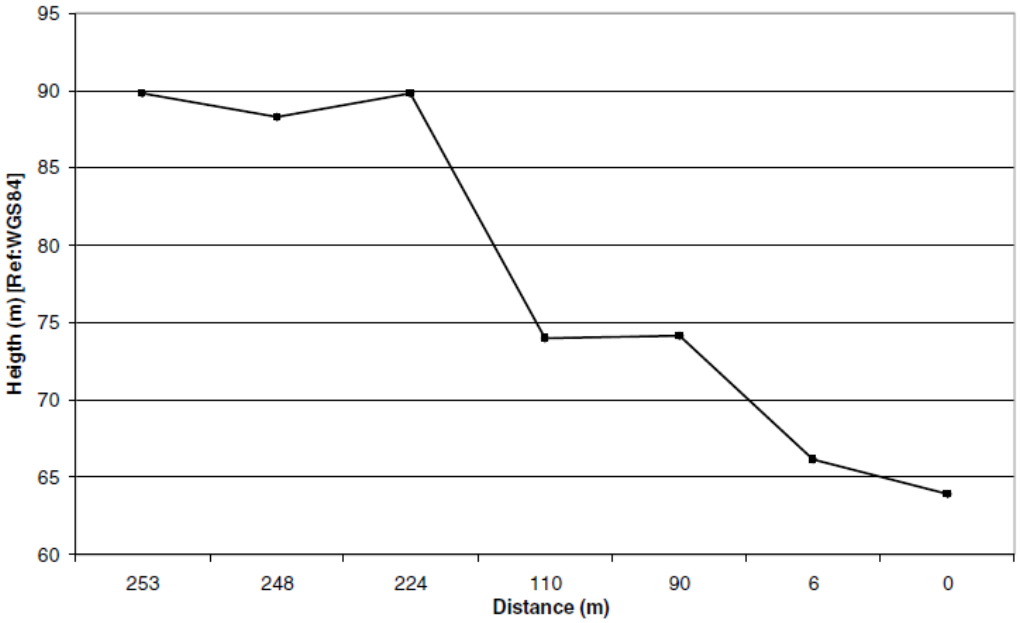

Figure 12 Uaupes River bed slope. Uaupes River bottom slope profile.

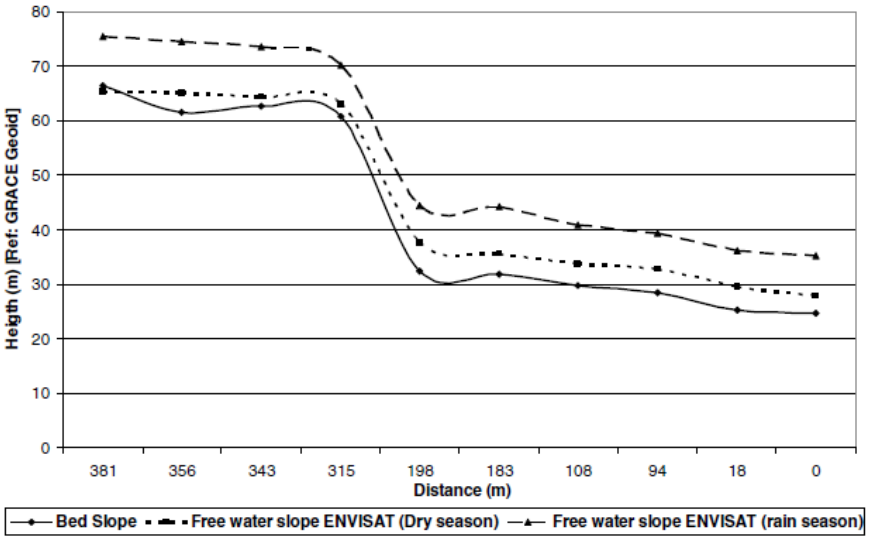

Figure 13 Negro River free water slope and bed slope. Upper Negro River free water slope calculated from ENVISAT altimetry data in dry and rainy season; and estimated bed slope.